

High-Frequency Broadband Acoustic Scattering from Temperature and Salinity Microstructure: From Non-Linear Internal Waves to Estuarine Plumes

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LONG-TERM GOALS

To understand high-frequency broadband acoustic backscattering from small-scale physical processes, such as internal waves, turbulence, and microstructure, in shallow, stratified coastal waters.

OBJECTIVES

The primary objective of the proposed research is to measure high-frequency broadband acoustic backscattering from temperature and salinity microstructure. Testing the validity of existing scattering models and the initial development of new, and/or extension of existing, simple physics-based scattering models is a secondary objective of this work. Specific goals include:

Goal 1: To measure high-frequency broadband acoustic backscattering in an energetic shallow water environment dominated by strong temperature gradients and high levels of turbulence, such as during the generation, propagation, and dissipation of non-linear internal waves during the SW06/NLIWI experiment. (FY2006, completed)

Goal 2: To measure high-frequency broadband acoustic backscattering in an energetic shallow water environment dominated by strong salinity gradients and high levels of turbulence, such as in estuarine plumes. (FY2007)

Goal 3: To analyze the data and compare the results to predictions based on existing physics-based scattering models with input parameters determined from almost coincident “direct” microstructure measurements. To use the measured broadband scattered spectra to determine regions in which the scattering is dominated by turbulence versus biology. In regions where the scattering is dominated by turbulence, to extract turbulence dissipation rates. To investigate possible anisotropy in the scattering by comparing the acoustic backscattering from side-looking deployments and down-looking deployments. (FY2006-2007, work in progress)

APPROACH

The approach taken here to understanding acoustic scattering from oceanic microstructure involves a combination of field experiments, data analysis, and interpretation within the framework of existing

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physics-based acoustic scattering models (Lavery et al., 2003), refining existing scattering models or guiding the initial development of new scattering models.

The approach taken here is to first perform measurements of high-frequency broadband acoustic backscattering in an energetic shallow-water coastal region in which there are strong temperature gradients. The idea is to maximize the contribution to scattering from temperature microstructure over salinity microstructure or biology. Scattering from marine organisms, predominantly small fish and zooplankton, which can act as passive tracers of physical processes such as internal waves and turbulence, are a significant confounding factor during the interpretation of high-frequency acoustic volume backscattering.

The data analysis involves capitalizing on the broadband nature of the transmitted signals and using pulse compression techniques (Chu and Stanton, 1998) to both increase the signal to noise ratio and the spatial resolution of the measurements. It has been possible to obtain almost cm scale resolution in the direction of acoustic propagation using these techniques, a great improvement over traditional single-frequency echosounder observations of water-column scattering. Additional information is obtained by further capitalizing on the broadband nature of the acoustic signals by using the spectral content of the scattering to determine if the scattering is consistent with scattering from small-scale physical processes or biology. In regions in which the scattering is determined to be dominated by turbulence, it may be possible to extract parameters such as the dissipation rate of turbulent kinetic energy. Direct measurements of microstructure and biology are important for allowing comparisons of acoustic measurements to physics-based model simulations.

The next stage of the project is to measure high-frequency broadband acoustic scattering in an energetic shallow-water coastal region with strong salinity gradients, such as estuarine plumes in which the fresh water river runoff mixes with more saline oceanic water. Though there is increasing evidence that scattering from thermal microstructure can be significant under certain circumstances, it has yet to be determined if scattering from salinity microstructure is significant, even in energetic environments with strong salinity gradients.

WORK COMPLETED

A 4-channel high-frequency broadband acoustic backscattering system (EdgeTech, Inc., Fig. 1) has been developed spanning the frequency range, in four overlapping bins, from 150 kHz to 590 kHz: the low-frequency channel spanning 150-270 kHz, the mid-frequency channel spanning 220-330 kHz, the high-low frequency channel spanning 330-470 kHz, and the high-high frequency channel spanning 450-590 kHz. The Airmar transducers (full beamwidths between 8 and 12 degrees depending on the frequency) are mounted on a rotatable frame that allows the transducers to be easily orientated in either a down-looking or side-looking mode (Fig. 1). The system is designed to either profile vertically with the transducers in a side-looking mode or to be suspended at a particular depth with the transducers in a down-looking mode (resembling a more traditional echosounder). A SeaBird SBE 49 FastCAT CTD (16 Hz sampling rate) is mounted on the system to measure fine-scale temperature and salinity gradients while in profiling mode. Pitch, roll, and heading are also measured.

The system has been calibrated in a sea-water tank and in-situ using a 20mm diameter Tungsten Carbide standard target. In addition, the beamwidth of each transducer has been measured, and

scattering from the flat air-sea interface in the sea-water tank has been measured in order to determine the frequency range over which each transducer has a flat frequency response.

This system has been deployed during the SW06/NLIWI experiment during a month long cruise (July 30- August 28, 2006) on the RV Oceanus in which direct microstructure measurements were performed by Jim Moum using the turbulence profiler Chameleon (Moum et al., 2003). The broadband acoustic system was fully operational throughout the experiment and high-frequency broadband acoustic backscattering has been measured for 28 internal solitary wave trains, in some cases chased from generation to dissipation stages. The acoustic system was deployed in both down-looking and side-looking mode, allowing scattering anisotropy during the passage of internal solitary waves to be investigated. In addition, 5 depth-resolved net tows (MOCNESS) were performed during this experiment in order to quantify the biological scatterers.

RESULTS

The data analysis from the SW06/NLIWI experiments is in its early stages. Highlights from the preliminary analysis are discussed briefly below:

Scattering due to small-scale physical processes versus biology: Though the frequency response of the scattering was predominantly consistent with scattering from biology (scattering increasing with increasing frequency), many regions were found in which the scattered frequency spectra were indicative of scattering from physical processes (Fig. 2). Such regions are being carefully analyzed to determine if physical parameters such as the dissipation rate of turbulent kinetic energy can be determined from the frequency response of the acoustic scattering.

Observation of an “empty” scattering layer: A layer of lower intensity scattering relative to the layers directly above and below it, or “empty” scattering layer, was often observed during the passage of the internal solitary waves (Fig. 2). Such an “empty” layer has been observed previously (e.g. Warren et al., 2003), and the mechanisms giving rise to such an “empty” layer are currently being investigated.

Shear instabilities: Each internal solitary wave (ISW) package was sampled multiple times during its evolution across the continental shelf using high-frequency broadband acoustic backscattering and direct microstructure measurements. In addition, the ISW were continuously sampled by means of an ADCP and a traditional 120 kHz hull-mounted echosounder. The high spatial resolution obtained with the high-frequency broadband acoustic backscattering measurements has allowed the progression of shear instabilities (Moum et al., 2003), suggestive of Kelvin-Helmholtz instabilities, to be observed at different stages of the ISW. These instabilities were not clearly observable using the lower spatial resolution traditional echosounder. The importance of such instabilities in the generation of turbulent overturns, and thus resulting in oceanic microstructure observable using high-frequency acoustic scattering techniques, is being investigated.

Scattering anisotropy: Thin horizontal scattering layers were consistently observed with the high-frequency broadband acoustic scattering system in down-looking mode (Fig. 2), across all frequency bands. However, significantly less structure was observed with the acoustic system in side-looking mode. Simple scattering models of thin shear layers are being investigated as a possible explanation for the strong anisotropy observed in the high-frequency acoustic backscattering.

IMPACT/APPLICATIONS

It is important to understand the circumstance under which different processes and/or targets contribute to high-frequency acoustic scattering. For example, a common misconception is that high-frequency acoustic scattering in the water-column is dominated by biological organisms. Only recently has it become more accepted that microstructure can also contribute to scattering, under certain circumstances. The results of the measurements performed here provide additional evidence that small-scale physical process can be significant contributors to volume scattering in regions of internal solitary waves. This project has also developed high-frequency broadband acoustic scattering techniques that 1) increase the circumstances under which scattering from microstructure and biology can be distinguished, and 2) increase the spatial resolution with which physical and biological processes are imaged, which is especially relevant as it has become increasingly evident that thin biological and physical layers are prevalent in coastal regions. Finally, these measurements may provide valuable environmental data to the SW06 community, in addition to potentially allowing high-frequency acoustic scattering techniques to become a useful remote sensing tool to physical oceanographers (such as the NLIWI community) to synoptically characterize and map the spatial and temporal distributions of certain small-scale physical processes.

RELATED PROJECTS

- Andone Lavery has received internal funding from WHOI to determine the extent to which multiple single frequency volume backscattering data from the Gulf of Maine can be used to discriminate between regions in which the scattering is dominated by turbulent microstructure and zooplankton. Regions of interest include internal waves propagating onto Georges Bank, for which the contribution to scattering from microstructure is expected to be elevated.
- Andone Lavery has received internal funding from WHOI to collaborate with David Farmer (University of Rhode Island Graduate School of Oceanography) on the effects of turbulence and microstructure on high-frequency acoustic propagation in Narragansett Bay. This project involves the analysis of data collected in Narragansett Bay with Farmer's ONR funded acoustical observatory with reciprocal transmission capabilities.

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STUDENTS ASSOCIATED TO THIS PROJECT

Doris Leong, Graduate Student, Dalhousie University, Canada.
Paul Heslinga, WHOI Guest Summer Student, Cruise Participation. July-August, 2006.

HONORS/AWARDS/PRIZES

Andone C. Lavery has received a Coastal Ocean Institute Fellow award from the Woods Hole Oceanographic Institution to investigate the effects of turbulence and microstructure on high-frequency acoustic propagation in Narragansett Bay using reciprocal transmission techniques.

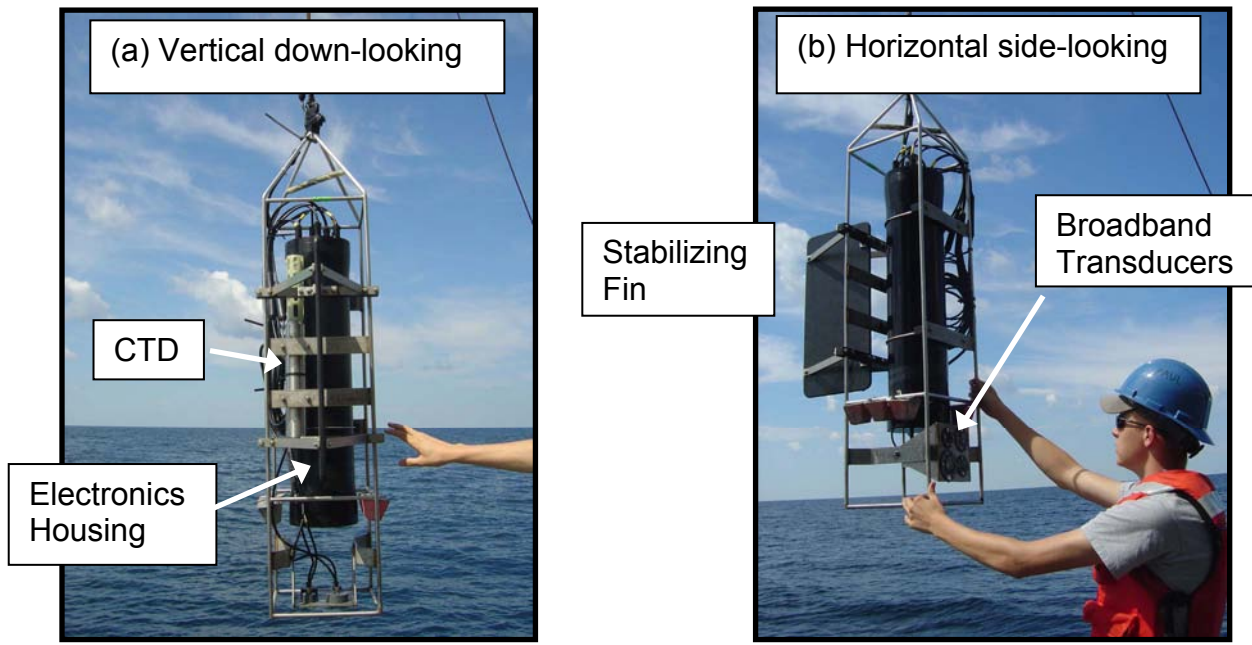


Figure 1. [Deployment of the combined high-frequency broadband acoustic backscattering and CTD system from the RV Oceanus in August 2006 as a part of the SW06/NLIWI experiment. (a) Vertical down-looking mode and (b) horizontal side-looking mode.]

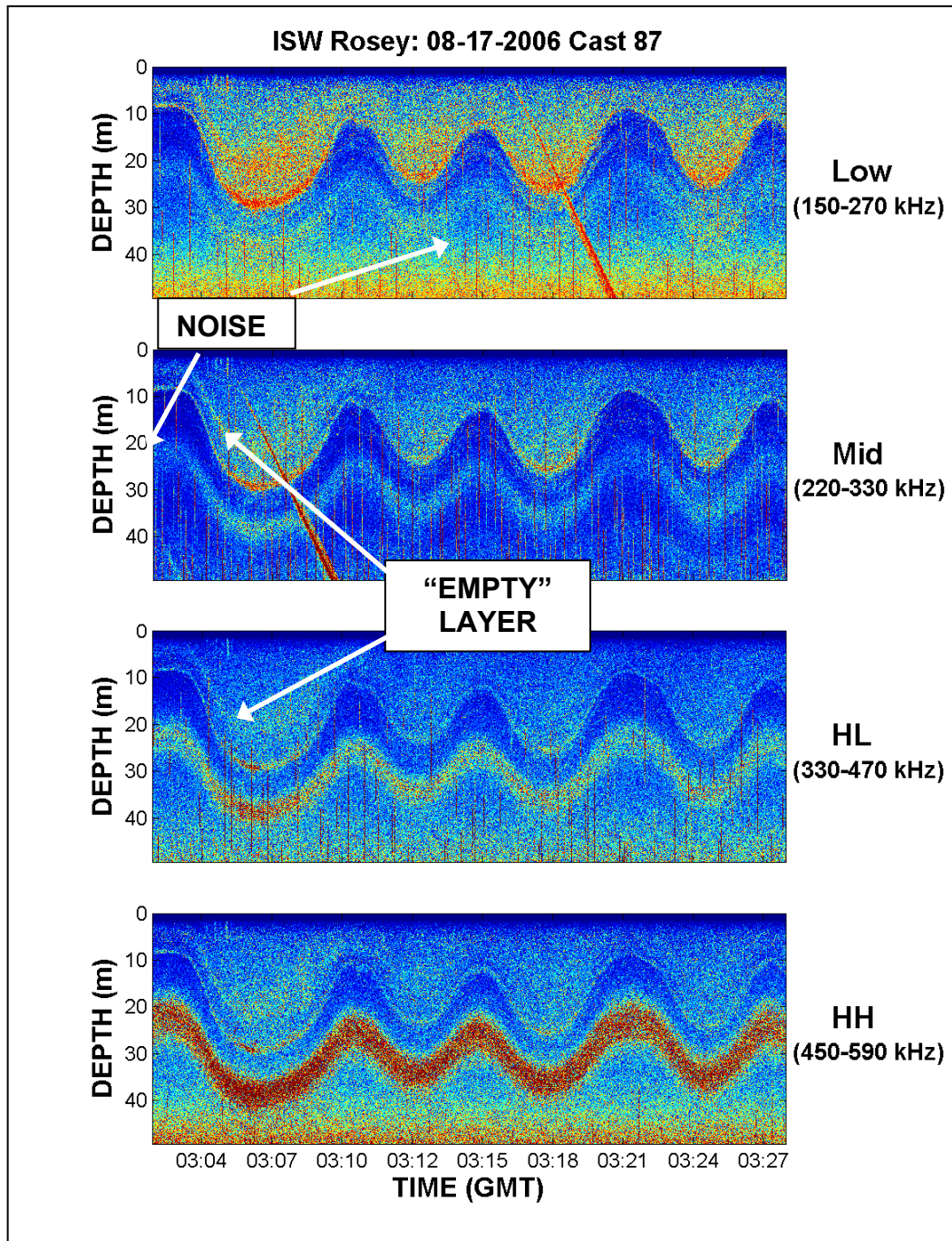


Figure 2. [Compressed pulse output of high-frequency broadband acoustic backscattering from a non-linear internal solitary wave on 17 August 2006 in the four overlapping frequency bands of interest. Multiple scattering layers can be observed with different frequency responses. A ubiquitous feature observed during this experiment was an “empty” scattering layer in which there was lower intensity backscattering across all frequency bands, relative to the higher intensity layers above and below it.]